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ABSTRACT

Changes in ship design or specifications disrupt work on a ship, and can disrupt work throughout an entire shipyard. This increases costs. Additionally, government-directed changes may be the legal basis for claims when the contractor overruns cost and schedule for any reason. Outstanding claims for equitable adjustment based primarily on alleged delay and disruption due to Government changes reached the unprecedented level of $2.5 billion in 1978. Many within the Navy would like to move the disruption issue out of the courts by paying the full cost of changes as they are implemented. This paper reports a test of the feasibility of a statistical method for fully pricing shipbuilding change manhours.

INTRODUCTION

In the summer of 1978, the Navy settled most of the $2-1/2 billion in contractor claims outstanding against several shipbuilding programs. At that time, Assistant Secretary Hidalgo's office issued the "Shipbuilding Procurement Process Study," which makes several recommendations for reducing the potential for claims in future programs. One recommendation is that the Navy consider new contract clauses for handling the changes in ship specification and design that inevitably arise in the course of a shipbuilding project. Changes have been the focus of controversy in claims proceedings both because they provide the necessary legal basis for claims when the contractor overruns, and because their costs typically have been disputed. One method for handling changes is for the Navy and contractor to agree on a way to set a price for full payment of change costs that both sides accept as fair and binding. Such an agreement would make it clear how much changes cost the Navy and would provide a framework for deciding who is responsible for costs that are not paid under the basic contract. Of course, as the past controversies over claims testify, costing changes has always been a very difficult and inexact art. Current change pricing systems either do not provide for full costing, or involve complicated subjective judgments. We therefore consider using a statistical model to estimate the total costs of changes. A statistical model is potentially simple, objective, and (on average) accurate. In this study, we describe such a model and report the findings of our tests of the feasibility of using it to estimate the total cost of changes.

Our statistical model yields manhour cost estimates for changes, which consist of three components. The first, the hardcore cost, is the contractor estimate of the net cost in labor hours needed to accomplish the tasks specified by the change. Hardcore costs are audited and may be negotiated downward but they generally are not disputed. We use hardcore hours in this study as an indicator of the "size" of the change.

The second and third components are the direct and indirect disruption costs. Changes in ship design or specifications disrupt work on a ship, and can disrupt work throughout an entire ship yard. This increases costs, and we define disruption costs in general as the total of these added costs, above the hardcore costs.

The disruption costs that occur for a given workforce and work week are called direct disruption costs. Indirect disruption costs are the added costs that occur if the contractor responds to the change by adding workers or increasing overtime. We estimate direct and indirect disruption costs statistically. We then compute the total cost of a change as hardcore costs plus direct disruption costs plus indirect disruption costs.(1)

It should be noted that only costs that are statistically related to changes are included in direct and indirect disruption. Changes and disruption due to changes are only part of the reason why ships cost more than the contractor's bid. We also estimate the independent effect on efficiency of shipyard manning, labor turnover, and labor skills

This report summarizes our study and findings. We first describe the role of changes and disruption in past shipbuilding claims, and how our study supports recent efforts to avoid claims. The second section describes how we estimate the total cost of changes. Findings for our applications of the statistical cost model to the FF 1052 and DD 963 programs are reported in the third section. In the fourth section, we briefly outline how a change-pricing system based on a statistical cost equation could be put into practice. Conclusions follow.

Change Pricing and the Navy's Program to Reduce Claims

The shipbuilding claims problem has its roots in the progressive procurement policies of the mid-1960's. Under the leadership of Secretary MacNamara, the Department of Defense implemented procurement policies designed to increase suppliers' incentives to hold down costs. It became standard policy to use fixed price contracts or cost sharing contracts for all Naval shipbuilding. Another new policy was total package procurement which the Navy used for the Amphibious Helicopter Assault Ship (LHA) program and the Spruance Destroyer (DD 963) program. Total package procurement combined the responsiblity for design and production in one contract. In theory, these procurement policies limited the Navy's responsibility for cost growth. In practice, when the Navy made design and specification changes, it became potentially liable for cost overruns just as under a cost-plus contract. The difference was that under the new policies the contractor had to file a claim to get additional compensation. This is the fundamental reason why changes led to claims in the late 1960's and 1970's. Although changes as a percentage of total work were little different from the 1950's, claims became a substantial part of shipbuilding costs.

Of course, these policies alone are not sufficient to explain claims. Claims would not have occurred without overruns, and inflation combined with limited cost escalation coverage helped produce overruns. Changes also contributed to overruns, but more importantly, changes provided the necessary legal justification for claims. When contractors had overruns, they blamed these changes. The Navy countered that changes were only partly to blame. Negotiations frequently broke down, and as a result, virtually every shipbuilding program completed in this period resulted in a claim.

The "Navy Ship Procurement Process Study," issued by Assistant Secretary of the Navy (M,RA&L) Hidalgo was aimed at finding ways to avoid claims in future programs. Many of the study's recommendations would reverse the new policies of the 1960's, and return more of the responsibility for costs back to the Navy. Among other things, the study recommended cost-plus contracts for early ships in a program, more liberal escalation, and more cooperation between the Navy and shipbuilders in planning programs.

The Hidalgo initiatives should reduce the severity of claims. They do not eliminate changes or the potential for later claims against unpriced changes. The fee the contractor earns on cost-plus contracts will to some degree depend on how well he meets cost and schedule targets, so changes could lead to disputes over how targets should be adjusted when changes are made. Of course, the size of potential claims in fixed price programs is reduced by the more liberal escalation clauses, but the potential for a claim nonetheless continues to be high.

To reduce the risk of claims the Navy now wants to find a better way to handle changes within the context of the basic contract. One way of doing this is for the contractor and the Navy to agree on a method for pricing the full cost of changes. The Naval Sea Systems Command (NAVSEA) is currently evaluating full pricing plans that fix total disruption costs in relation to hard-core change hours. Using disruption "cost factors," program managers would periodically negotiate and pay the total cost of current changes. To be acceptable, however, such payments must be realistic and fair to both sides. Thus, successful full pricing requires a method for estimating the total cost of a change which is accurate and agreeable to the Navy and the contractor. If such a method can be devised, and full pricing instituted, the risk of claims can essentially be eliminated.

METHOD FOR ESTIMATING THE TOTAL COST OF CHANGES

The Navy is legally responsible for hardcore change and disruption costs under the doctrine of "equitable adjustment." However, there is no clearly established method of calculating the amount of the equitable adjustment. The problem is one of identifying all relevant costs.(2)

The hardcore costs of changes can be estimated using accepted industrial standards. These costs are associated with specific identifable tasks that are added or deleted by the change. However, disruption cannot be tied to specific change related tasks. Part of direct disruption costs result because changes may have a synergistic effect on efficiency over a number of ship systems, cost centers, or programs. Indirect disruption results because the contractor responds to changes by altering the schedule, workforce or the amount of overtime worked, which also has an effect which is not localized to a particular change. It would be impossible through established accounting procedures, to objectively identify these disruption costs with a specific change.

We estimate the total cost of changes by showing how the manhour cost of a ship varies as hardcore change hours are added. We first developed a model of shipbuilding and derived a statistical cost equation. The parameters of the equation were estimated using data collected for the variables in the equation. The coefficients of the equation show how each variable affects total manhour costs when all other variables are held constant. We use these estimated coefficients to calculate the total cost of changes. This work is described in detail in the remainder of this section.

The Model

Our theoretical analysis of the shipbuilding process identified the major variables that, in theory, explain the total manhour costs of a ship.(3) Shipbuilding is a very complex process, and the full range of variables that figure into the cost of a ship is very large. A general shipbuilding cost equation would require variables describing the ship, the shipyard, including other work, the work force, contract terms, Navy and shipyard management, and program changes and delays. An equation that incorporated all these variables would show what any kind of ship would cost in any shipyard. We focus on the more manageable task of explaining the total manhour cost of a given kind of ship in a given shipyard during a specific time period.

The theoretical analysis suggested that the following groups of variables should be included in the cost equation: (i) learning - which reflects productivity increases as more ships of one kind are built; (ii) a measure of the changes made to each ship; (iii) variables measuring work force productivity - such as yard or program manning, work force skills and experience, and the amount of overtime worked. We also consider the effects of (iv) delay; and (v) the manning level of other programs in the yard.

Changes and some of the other variables present difficult measurement problems. A change, for example, has many dimensions, including the number of hardcore manhours, hardcore material costs, the trades affected, the compartment or ship systems affected, and whether it is implemented early or late in the construction process. Conceptually, there is no problem in describing all the variables perfectly. There are practical limitations, however, and the equation will be more easily understood if the number of variables can be kept small. For example, we use only hardcore change hours to measure the size of a change. This undoubtedly limits our ability to precisely estimate how the cost of changes depends on variables such as those listed above. However, as we shall see, hardcore changes appear to serve very well to measure the effect of a change on total manhour costs. Using a limited number of variables, we are able to explain most of the variation in manhours across ships. In future applications, the number of explanatory variables could, of course, be expanded to obtain whatever level of detail is necessary.

The cost equation for our empirical analysis takes the general form shown in equation 1 below. The cost equation is applied to data measured for an interval of time. The average manhours used per unit of output in the period is the dependent variable. The right hand variables are either totals for the period (for example, total hardcore change hours) or are averages over the period (for example, the average number of workers, the average experience level of workers, and so forth):

$$\ln(MH/Q) = A + a \ln M + b \ln H + c \ln EX + d \ln SK + e \ln N + f \ln HC + g \ln MO + h \ln D + u \quad (1)$$

where: ln means "natural logarithm of"
- MH = manhours applied to a ship during a given period
- Q = output (physical completion of a ship during a given period)
- A = constant term
- M = number of workers
- H = average hours per work day
- EX = experience of work force
- SK = skill level of work force
- N = ship construction sequence (related to learning; the efficiency improvement for each subsequent ship)
- HC = hardcore change hours
- MO = manhours applied to other programs
- D = delay in ship delivery
- u = statistical error term
- a,b..,h = coefficients (manhour elasticities)

The coefficient of each variable shows how total manhours change for given output when the value of one variable changes, and all the other variables remain the same. For example, the coefficient of a skill variable shows how manhours would change if skill level increased while learning, changes, manning, experience, etc., are held constant. Thus, these coefficients show the quantitative relationship between manhours and each of the explanatory variables.

Calculating the Cost of Changes

The coefficient of hardcore change hours shows the percentage increase in total manhours for a one percent increase in hardcore change hours, when all the other right hand variables are held constant. Thus, this coefficient measures direct disruption costs.

To obtain a standardized unit for comparative purposes, we express direct disruption in terms of hours per hardcore change hours. We calculate this as follows: first, we compute from the change coefficient the implied increase in manhours for each hour of hardcore change work. This is called the total unit cost of changes. Then, we subtract the hardcore hour from this total. For example, if the change coefficient indicates that total manhours go up by say 2-1/2 hours, one hour is hardcore, and the additional 1-1/2 hours is direct disruption.

The indirect cost of changes equals the costs due to increases in the work force, or overtime that are, in turn, due to changes. Our equations include these variables, so the costs of such adjustments are not included in the direct disruption cost. We must calculate these indirect disruption costs independently. To estimate the indirect cost of changes, we first have to estimate how changes affect manning, and overtime. We then calculate the effect of these variations on manhour costs. For example, if changes cause manning to increase by ten percent, the indirect disruption cost equals the estimated manhour cost associated with this increased manning. The sum of direct and indirect costs equals total disruption. The total cost of changes equals the sum of total disruption plus the hardcore cost.

EMPIRICAL ANALYSIS OF TWO SHIPBUILDING PROGRAMS

We applied the methodology outlined in the preceding section to the Avondale FF 1052 and Ingalls DD 963 shipbuilding programs to test our ability to explain manhours and estimate the manhour cost of changes. In this section, we describe our analysis of these programs and report the findings.

Our equations proved very successful in explaining the total manhours used for the ships in these programs. We were able to explain more than 90 percent of the variation in production manhours across data points in each program. When we broke the Ingalls data down into seven labor departments, we typically were able to explain between 60 and 70 percent of the variation.

Several versions of the statistical equation were estimated for each program. The findings were generally consistent across these different equations. Thus, we report a subset of findings, which are representative of what we discovered.

Our calculated unit costs of changes vary, depending on certain shipyard labor characteristics, and the magnitude of changes relative to total work on the ship. When calculated at the sample means of these variables, we estimate the unit cost of changes for all production labor to be about 3.5 hours for the FF 1052 program and 2.5 hours for the DD 963 program. For the DD 963 program the unit costs ranged from a low of 1.4 hours for the sheet metal department to a high of 4.4 hours for the paint department.

THE UNITS OF ANALYSIS

The units of analysis are described in table 1. The data are observed for 24 ships of the FF 1052 program. A total of 56 annual observations of 26 different ships are used for the DD 963 analysis. We analyzed seven labor departments individually as well as total operations manhours for the DD 963. The basic methodology is the same in both cases.(4)

VARIABLES

Our equations include as right-hand variables hardcore change hours along with manning, labor skills and experience, ship construction sequence number, and sometimes overtime and delay. The variables used in the analysis are listed in table 2.

We also considered interactions of changes with manning and turnover. Including these variables along with changes allows us to predict the effect of changes on manhours for different levels of manning or turnover.

It is important to emphasize that the unit of observation is not an individual change. We use the total hardcore hours for all the changes implemented in the observation period to explain the manhours in the period. However, over the many changes included in each observation, the individual differences tend to average out, and hardcore manhours are a good measure for the overall impact of changes.

Table 1. Units of analysis for the Avondale FF 1052 and Ingalls DD 963 programs

	Avondale FF 1052	Ingalls DD 963
Observational units:	Each ship.	Annual observation on each ship, fiscal years 1975 - 1978.
Sample size:	24 ships.	56 observations on 26 ships.
Manhour variables:	Total production manhours.	Manhours for: Total operations[a] Hull Manufact. services Pipe Outside machinists Sheet metal Paint Electrical

[a]Ingalls Total operations includes nearly the same crafts as Avondale Total production .

Table 2. Variables used to explain manhours

	Avondale FF 1052	Ingalls DD 963
Learning:	Ship construction sequence number	Ship construction sequence number
Manning:	Hull manning (equivalent men)	Yard operations and cost center labor (payroll) LHA program labor (equivalent men) Submarine overhaul labor (equivalent men)
Labor skills and experience:	Labor turnover rate (annual)	Journeymen/Total labor percentage Labor turnover rate (quarterly)
Overtime:		Overtime hours
Changes:	Negotiated change hours plus Navy claims team estimate of unnegotiated hardcore hours	Estimated production work added change hours
Delay:	Total delay in ship delivery	Change in estimated completion date during period (days)
Construction output:	The total ship	Manhours earned in period adjusted for changes in plan
Interaction variables:	Changes x turnover	Changes x manning Changes x turnover

FINDINGS

Our findings demonstrate the importance of learning, changes, manning and labor skills and experience in explaining manhours.

Estimates of the Regression Equations

The regression estimates for total production manhours for the FF 1052 and DD 963 programs are presented in table 3. Across from each explanatory variable is its coefficient (elasticity) estimated for each program. The elasticity of manhours with respect to a given variable is the percentage change in production hours that would result from a one percent increase in the explanatory variable with all other explanatory variables held constant.

Table 3. Findings for equations explaining total production manhours for FF 1052 and DD 963

Explanatory variable	Manhour elasticities FF 1052 program	DD 963 program
Learning	-.182	-.361
Changes	.285*	.053**
Yard manning		.439**
Hull manning	.248	
Manning x change interaction		.519
Yard turnover	.667*	
Turnover x change interaction	.953	
Submarine program		.407
LHA program		.184
Delay	.143	

*Computed at sample mean values of changes and turnover
**Computed at sample mean values of changes and manning

The FF 1052 Program. Our equation explained 99 percent of the variation in the natural logarithm of manhours used to build the 24 FF 1052's we observed. All of the variables were significant at the .95 level in explaining total manhours.

The learning coefficient shows that when the number of ships completed is doubled, the cost of the last ship in the second goup is 18 percent below the cost of the last ship in the first group. This translates into a learning rate of 88 percent.(5) Learning was actually better than the learning bid by Avondale.

Increased hull manning led to increased manhour requirements. Each one percent increase in hull manning is predicted to increase manhour requirements by about 1/4 of one percent.

We found that the coefficient for hardcore changes depends importantly on labor turnover. Changes are more costly when they are made during periods when turnover is high. The turnover hardcore change interaction coefficient of .953 implies that a one percent increase in turnover increases the manhour cost of a change by nearly one percent. The reported change and turnover coefficients are computed for the sample mean values of turnover and changes.

Delay was a very important determinant of manhours in the FF 1052 program. This is not surprising. This program was marked by many delays due to late delivery of plans, specifications, and equipment. The delay coefficient shows that every one percent increase in ship delay increases the manhour cost of the ship by .143 percent. This figure implies that a one month increase in delay increased manhour costs by 51 man months (8200 manhours). The positive and significant coefficient of delay suggests that delay was predominantly exogenous (bottleneck delay due to missing plans, specifications or equipment) rather than discretionary.

The DD 963 Program. Our equation explained about 94 percent of the variation in the natural logarithm of total operations manhours across the 56 observations on the DD program.

Manning dominated all other labor variables in explaining manhours in this program. This variable is a proxy for labor quality. As manning increased it became more difficult to hire the desired number of quality workers. The other labor variables (overtime, turnover, and the percent of the work force that were journeymen) were insignificant when the manning variable was included in the same equation. Thus, these variables are not included in table 3. These variables are highly correlated with manning, and although they are important determinants of manhour costs, the data do not allow us to sort out their independent effect on costs. Each of these variables is significant for total operations labor and some of the individual production departments when manning is excluded.

The estimated learning coefficient is -.361. This implies a learning rate of 78 percent when other factors are held constant. To an even greater extent than for the FF 1052, this estimated learning exceeds the learning incorporated in the original bid. Litton was not able to get its high- efficiency assembly line type production process into operation as quickly as planned. The LHA's also were in the yard longer than intended, which to some extent limited the availability of facilities and forced the use of more workers in the yard than intended. This learnng therefore partly reflects the breaking in of the new yard, a move to the planned production process, and diminishing influence of the LHA.

We found a significant interaction effect between hardcore change hours and yard manning. The coefficient implies that a one percent increase in manning increases the cost of changes by .519 percent. The coefficients of manning and changes shown in table 3 are computed at the sample mean values of changes and manning.

Yard manning, submarine program manning, and LHA program manning must be interpreted together. These three variables represent two interdependent effects. One is the effect of total yard manning on productivity. The other is the effect of programs competing for facilities and labor quantity and quality.

When total yard manning goes up, holding submarine and LHA manning constant, the added workers by definition go to the DD 963 program. Thus, the yard manning coefficient shows that a one percent increase in DD 963 manning, holding the other programs constant, increases manhour requirements by .439 percent.

The submarine and LHA variables show the effect of adding men to these programs while holding total yard manning constant. Both effects are positive. A one percent increase in submarine workers at the expense of the DD 963 program increases DD manhour requirements by .407 percent. A one percent increase in LHA workers increases DD manhour requirements by .184 percent.

Since yard overmanning due to the delay of the LHA is considered a major factor in Ingalls' production problems, we expected the manning of the LHA to be a significant variable in explaining DD 963 manhours. The significance of the submarine program variable is somewhat surprising. The submarine work is physically separated from the other programs, and the submarines never accounted for more than eight percent of the yard's operations labor work force. However, some observers conjecture that the submarines were sometimes given the most highly skilled workers at the expense of the other programs. In addition, the time pressures of the overhaul work might also have diverted a disproportionate amount of management attention to this work.

The DD 963 Program by Labor Department. Table 4 summarizes the qualitative findings for seven Ingalls production departments. We report the same basic specification as used for the overall analysis. This includes the manning-change interaction term as well as any additional variables that are significant. Across from each variable are the findings for each of the seven departments, which are listed across the top. With the exception of delay and ship sequence number, all of the variables are measured separately for each of the labor departments. A plus sign or minus sign shows the direction of effect when the variable is significant in explaining department manhours. A blank indicates the variable was not significant for the base case estimates.

Learning is the only variable that is significant across all departments. The hardcore change hours variable is significant for all departments but one. Either the turnover-change or manning-change interaction variable was significant in every case. These qualitative findings are consistent with the findings for total operations manhours.

Considerable differences exist among the labor departments. This is readily apparent from our qualitative findings.

The yard manning variables show the effect of building up manning of the DD 963 program while holding constant the manning levels of the other two programs. This means manhours fell (efficiency rose) as more men were added to the hull, outside machinist, paint, and sheet metal departments. We conclude that these departments were generally manned below their optimum levels so that efficiency rose as manning increased. This is consistent with the manning history for these crafts.

In the basic specification, turnover is significant for three departments (outside machinist, paint, and sheet metal). Three departments (pipe, paint and electrical) have significant turnover-change interaction effects when this variable is entered in place of the manning-change interaction. Pipe, machinists, and electrical typically require highly skilled workers which were chronically in short supply. This could explain why turnover is more of a problem for those departments.

The percent journeymen and overtime variables were significant in a few cases. However, the percent journeymen variable was never significant when entered with yard manning. For most departments, this variable closely followed yard manning; when the yard was building up, journeymen fell as a share of the total work force. Thus, we can't distinguish the effect of this variable from the effect of yard manning.

Overtime was significant in two departments. It was anticipated that overtime increases manhour costs. This was the finding for the hull department. However, we find manhour requirements were reduced by using overtime in manufacturing services. The manufacturing services department performs support functions for the other departments and includes carpenters and launch pontoon personnel. These workers play a key role in events such as launch where timing is critical. One interpretation consistent with our findings is that schedule adherence and proper sequence are particularly important contributors to efficiency for manufacturing services. Thus, the use of overtime is an efficient use of manhours.

The delay variable did not significantly add to our ability to explain total operations manhours. We find, however, that delay is significant in two labor departments. Sheet metal department manhour requirements were greater the longer was delay, but pipe department manhour requirements were lower. This pattern of results supports the report of many observers that the pipe department was the most critical craft. The negative delay coefficient indicates that the original ship delivery schedule required the pipe department to work at a faster than efficient rate. Thus, efficiency rose when a ship was delayed.

Table 4. Qualitative findings for equations explaining manhours for major Ingalls labor departments

EXPLANATORY VARIABLES	INGALLS' LABOR DEPARTMENTS: HULL	MFG. SERVICES	PIPE[a]	OUTSIDE MACH.	PAINT[a]	SHEET METAL[a]	ELECTRIC
LEARNING	-	-	-	-	-	-	-
CHANGES	+	+	+		+	+	+
YARD MANNING	-	+		-	-	-	+
MANNING - CHANGE INTERACTION	+	+			+	+	+
TURNOVER				+	+	+	
OVERTIME	+	-					
SUBMARINE PROGRAM			+	+	+		
LHA PROGRAM	+						+
DELAY			-			+	

[a]The manning-change estimates represent the base case, and all the findings in the table apply to that case. However, for these shops the turnover-change interaction is significant, and yields greater explanatory power than the base equation.

The Manhour Cost of Changes

In this section we use the estimated coefficients of the cost equations to estimate tht total cost of changes. We also examine the sensitivity of the cost of changes to varying levels of manning and turnover.

The FF 1052 Program. The direct disruption cost is sensitive to the level of turnover. Direct disruption varies between .81 and 2.67 when turnover is varied 10% below and 10% above the mean value of 60%. At the mean of turnover, direct disruption is 1.78 hours per hardcore change hour.

Some delay was caused by changes and is therefore related directly to hardcore changes. To identify the indirect disruption cost of delay due to changes, we estimated the equation shown in

table 3 but with delay omitted. Using this estimate of the change elasticity we calculated the indirect disruption cost of delay as .5 manhours per hardcore change hour.

Omitting manning from the estimating equation resulted in a serious misspecification so we estimated the indirect effect of this variable differently. On average, change hours accounted for 10-1/4 percent of total hours. These additional hours could have been put in partly by hiring more workers and partly by delaying the program. We assume that 10 percent more men were hired. Turnover was not positively related to ship manning for this program so we assume turnover was not affected.

Our findings for manning imply that a 10 percent increase in manning increases total manhour costs by about 2-1/2 percent. This is roughly 1/4 hour of indirect disruption for each hour of hardcore change work.

The total cost of one hardcore hour of change is shown in table 5.

Table 5. Estimated total cost of one hardcore hour of change for the FF 1052 program at mean values

1.00	Hardcore change hour
1.78	Direct disruption costs
.50	Indirect cost of delays due to changes
.25	Indirect cost of 10 percent added ship manning
3.53	TOTAL

Table 5 shows that total disruption equals 2.5 hours per hardcore change hour.

The DD 963 Program. For total operations, direct disruption is 2.48-1=1.48 manhours per hardcore hour of change work. This estimate is sensitive to variations in yard manning. Estimated direct disruption is only .36 hours when manning is 10 percent below average. Direct disruption is 2.62 when manning is 10 percent above average.

The direct disruption costs of changes varies considerably among labor departments. Four departments are below the direct disruption cost for total operations. The sum of hardcore and direct disruption costs for these departments are 1.05 manhours for sheetmetal, 1.75 manhours for the hull department, 1.94 for outside machinists, and 2.26 manhours for manufacturing services, when calculated at the mean manning level for each department.

For the three labor departments employing the most highly skilled crafts - pipe, machinists, and electrical - the sum of hardcore and direct disruption costs ranged from just under 2 hours to nearly 4 hours. The highest cost of 4.36 manhours was for the paint department, which accounted for only a few hours for each change. Thus, paint direct disruption was small in absolute terms, but large relative to the small number of hardcore change hours.

The sensitivity of direct disruption to variations in manning also differed among the crafts. Pipe and sheetmetal costs were not very sensitive. A hypothetical variation in manning of $\pm$ 10% led to less than 1/4 hour variation for pipe and the variation was negligible for sheetmetal. The costs of the manufacturing services department was most sensitive to manning variations. The sum of hardcore and direct disruption costs actually fall below one, implying negative disruption, when manning drops 10 percent below average for this department. This can be explained by the small variation in manning for this craft. The 10% change in the natural logarithm is 14.5 standard deviations from the mean. We are therefore examining this variable at a point well outside its normal range.

These findings show that there is a great deal of variation among the departments. However, the pattern of the findings is consistent with the expected relative magnitudes of direct disruption costs for the various departments. The pipe, paint and electrical departments, crafts which are expected to be more susceptible to disruption because of the nature of their work, have greater estimated direct disruption costs.

The paint cost center shows the highest direct disruption cost. This finding is consistent with a craft which requires a lot of set up time for the amount of work done on each change. Additionally, change work for painters is frequently brush work, as opposed to original work where an entire compartment can be prepared and sprayed.

The indirect disruption costs of changes are small for this program. There are several reasons for this. First, DD 963 program changes represent

a small fraction of the total work in the Litton yard, so workforce adjustments due to changes were minimal. In addition, our findings for several departments indicate that manning was limited by the supply of workers, making adjustment for changes infeasible. Second, delay or overtime are significant in the cost equation for only four crafts. The variables were not in the equation explaining total operations manhours, so the costs of delay and overtime related to changes are already included in the change variable coefficient.

Net DD 963 hardcore change hours amount to only about 2 percent of the total manhours used to build each ship. If we were to suppose that DD manning increased 2 percent in response to changes, the implied indirect effect of manning would be .22 manhours per hardcore hour of change work. However, examination of the data indicates that manning did not respond positively to changes. We therefore believe that this indirect effect was negligible.

Manning coefficients were negative for the hull, outside machinist, paint and sheet metal departments. This implies that the net effect of a labor force buildup due to changes would be to reduce manhours. The available evidence indicates that these negative coefficients reflect Ingalls' difficulties in hiring and retaining workers at some times in the program. Thus, the size of the workforce was determined mainly by hiring and retention problems, and did not respond to changes.

Overtime was significant for two labor departments (hull and manufacturing services). However, the correlations between overtime and changes are negative and small for these crafts. Thus, we conclude that although overtime is significant, there were no appreciable overtime costs due to changes for these crafts. This is in agreement with the fact that the contractor generally did not include additional overtime in his change proposal estimates.

Delay was not a significant variable in the equation explaining total hours. Delay was closely correlated with changes. Thus, any delay costs are included directly in the costs of changes. Delay was significant for the pipe and sheet metal departments. Table 6 presents the calculations of the indirect delay costs of changes for these two departments. We found that delay reduces costs for the pipe department, so it is not surprising to find that delays attributed to changes also reduce costs. Thus, the indirect unit cost of delay is negative.

The sheet metal costs are positive, and about the same magnitude.

Table 6. The indirect costs of delay in the DD 963 program (pipe and sheetmetal departments)

Department	Unit cost without controlling for delay	Unit cost controlling for delay	Difference
Pipe	3.18	3.51	-.33
Sheet metal	1.39	1.05	+.34

Indirect disruption costs for the DD 963 are small in all but one case. This is consistent with a program where hardcore change hours were a small percentage of total manhours.

The total cost of changes is shown in table 7. Inclusion of the indirect effect of manning and overtime would require assumptions which do not appear to be warranted by our findings. There fore, the total unit cost of changes is essentially the same as the direct unit cost.

These are our best estimate of the cost of changes for the DD 963 program for the four fiscal years 1975-1978. We believe they are representative of the actual cost of changes for that program in the time period analyzed.

A SYSTEM FOR PRICING CHANGES

The estimation results summarized in the preceding section show that it is practical to estimate the total cost of changes using a statistical cost equation. We believe the estimates of total change costs derived from this equation are sufficiently accurate to serve as the basis of a change pricing system. Work remains, however, before such a system could be put into use. In this section, we discuss some of the issues that need to be resolved in developing a practicable change pricing system based on a statistical cost estimating equation.

Implementation of the system to price changes requires three basic steps: (i) At the outset of the program, the Navy and the contractor must agree on the equation to be used; (ii) periodically, say every three months, the

Table 7. Estimated total cost of changes for the DD 963 program (fiscal years 1975-1978)

	Total production	Hull	Mfg. services	Pipe	Outside machinists	Paint	Sheet metal	Electric
Hardcore hour	1	1	1	1	1	1	1	1
Direct disruption cost	1.48	.75	1.26	2.51	.94	3.36	.05	2.93
Indirect disruption cost of delay				-.39			.34	
TOTAL COST for each hour of hardcore change work	2.48	1.75	2.26	3.12	1.94	4.36	1.39	3.93

equation would be estimated and the total cost of changes for the program calculated; and (iii) these cost estimates would be used to price changes for the following three-month period.

The test applications reported here used data from the DD 963 and FF 1052 programs that were collected for other purposes. The cost equation could be much more detailed in future applications. For example, our analysis of the DD 963 program shows that the equation can be applied for each labor department. However, the Ingalls Shipyard further breaks down accounting data by work area and ship system. If these data were used, the statistical cost equation could be applied for each labor department further broken down by work area, and/or ship system. In addition, this could make it feasible to include more detailed characteristics of changes and other variables. We believe a cost equation will be more accurate, and the resulting change pricing system more flexible, the more detailed we make it. But it is also more costly. Thus, one important issue that must be resolved is the required level of detail. Further experience will be necessary to determine the most cost effective level of analysis.

Another issue relates to how the statistical estimates of the total cost of changes will be used in pricing changes. The most straightforward approach is to use the estimates of the model to cost a change, and agree that this is the price that will be paid.

Alternatively, a more complex system could be devised in which the estimated change cost serves as a baseline, and the price to be paid negotiated from there. However, if such a system is adopted, some limitation must be placed on the range for negotiations; otherwise these negotiations could break down just as change pricing negotiations have broken down in the past.

The questions of whether the change price arrived at by such a system should be a fixed price, or have a cost sharing provision should also be resolved. Cost sharing, with a maximum price, would seem to be a good way to share the cost risk of a change while still limiting the Navy's total liability for the change.

The cost equation is designed to measure the contractor's actual cost of performing change work. It is Navy policy to provide equitable payment for changes. However, any system for pricing changes including the one outlined here must address incentives to increase the price above that which is equitable. First, of course, a system such as this limits the contractor's incentives to hold costs down, because if the contractor is inefficient in performing change work these inefficiencies will become embodied in the prices paid for changes. The second problem is that a system such as this gives the contractor incentives to negotiate higher hardcore costs than might be warranted. On the whole, we do not believe these problems are worse for this system than for other proposed methods for pricing changes, or for the systems used to handle changes today. Contractors always have an incentive to overstate the cost of changes, and the current system does not safeguard the Navy against contractor inefficiency.

In addition to the current system for auditing and negotiating hardcore costs, a statistical change pricing system would provide information about inefficiencies not associated with change as a further safeguard against overpayment.

These issues will best be resolved with practical experience in using a change pricing system. We believe the best way to gain this experience is by further experimentation with the system using data from an ongoing program.

CONCLUSIONS

Our analysis of the two programs show that:

(i) Actual learning exceeded bid learning in both programs. For the FF 1052 program actual learning when other sources of inefficiency are controlled for was only slightly better than bid. The very steep learning curves for the DD 963 program reflect substantial start up costs as the new yard was being broken in.

(ii) Changes affect production manhours significantly. Total disruption was 2.5 hours per hardcore change hour for the FF 1052 program and 1.5 hours per hardcore change hour for the DD 963 program.

(iii) Increased manning and labor turnover increase production manhours significantly.

(iv) The cost of changes depends on the values of these manpower variables

(v) Delay significantly affects production manhours independently of changes in the FF 1052 program, but not in the DD 963 program. This reflects the importance of bottleneck delay due to missing plans, specifications and equipment for the FF 1052. For the DD 963 delay was primarily decision delay and was highly correlated with changes.

(vi) Competing programs (LHA and submarine overhauls) had a measurable impact on DD 963 operations labor. This was also true for five of the seven individual departments.

These findings confirm what is generally believed to be the primary determinants of the costs of building a ship in a given shipyard. More than this, the regression estimates show the quantitative effects of the explanatory varibles in these two programs to be in good agreement with both theory and intuition.

We have shown the feasibility of allocating inefficiency to changes and to factors for which the contractor is generally considered responsible. This was done using the available data from historical shipbuilding programs. These statistical methods could be applied with even more precision and confidence using data gathering systems designed explicitly for estimating change costs. Thus, we believe this methodology holds considerable promise for fully pricing changes in future shipbuilding programs.

FOOTNOTES

(1)Note that direct and indirect disruption costs do not correspond to the classification most often used in the literature. Total disruption is generally defined as equal to local disruption plus program disruption. Our definition of direct disruption includes all change costs that are not due to adjustments in work hours or the work force; therefore, direct disruption includes more than just local disruption. However, in the absence of any error the sum of direct and indirect is the same as the sum of local and program disruption.

(2)In recent cases the courts have ruled that the contractor is entitled to "being made whole". This implies that he is entitled to the recovery of reasonable costs based on his position as a result of the change and his industrial practices. This is in contrast to the criterion of "fair market value" which implies payment commensurate with the industry costs at large. At the same time the contractor is obliged to mitigate against unreasonable costs such as failure to obtain the best available price for material.

(3)A full description of the theoretical model is available from the authors.

(4)Avondale FF 1052 program data covered the total construction period. Data limitations restricted analysis of the DD 963 to four years (July 1974-July 1978). Consequently, our findings for the latter program apply only to this four year time period.

(5)The learning coefficient is the percentage decrease in marginal cost for a one percent increase in the number of units. Learning rate is the cumulative average cost of 2x units expressed as a percentage of the average cost of x units. Note that the greater the learning rate the lower the efficiency gains for subsequent units.

PP 211
Mizrahi, Maurice M., "On Approximating the Circular Coverage Function," 14 pp., Feb 1978, AD A054 429

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Mangel, Marc, "On Singular Characteristic Initial Value Problems with Unique Solution," 20 pp., Jun 1978, AD AD58 535

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Mangel, Marc, "Fluctuations in Systems with Multiple Steady States. Application to Lanchester Equations," 12 pp., Feb 78 (Presented at the First Annual Workshop on the Information Linkage Between Applied Mathematics and Industry, Naval PG School, Feb 23-25, 1978), AD A071 472

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Weinland, Robert G., "A Somewhat Different View of The Optimal Naval Posture," 37 pp., Jun 1978 (Presented at the 1976 Convention of the American Political Science Association (APSA/IUS Panel on "Changing Strategic Requirements and Military Posture"), Chicago, Ill., September 2, 1976), AD A056 228

PP 215
Colle, Russell C., "Comments on: Principles of Information Retrieval by Manfred Kochen," 10 pp., Mar 78 (Published as a Letter to the Editor, Journal of Documentation, Vol. 31, No. 4, pages 298-301), December 1975), AD A054 426

PP 216
Colle, Russell C., "Lotka's Frequency Distribution of Scientific Productivity," 18 pp., Feb 1978 (Published in the Journal of the American Society for Information Science, Vol. 28, No. 6, pp. 366-370, November 1977), AD A054 425

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Colle, Russell C., "Bibliometric Studies of Scientific Productivity," 17 pp., Mar 78 (Presented at the Annual meeting of the American Society for Information Science held in San Francisco, California, October 1976), AD A054 442

PP 218 - Classified

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Huntzinger, R. LaVar, "Market Analysis with Rational Expectations: Theory and Estimation," 60 pp., Apr 78, AD A054 422

PP 220
Maurer, Donald E., "Diagonalization by Group Matrices," 26 pp., Apr 78, AD A054 443

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Weinland, Robert G., "Superpower Naval Diplomacy in the October 1973 Arab-Israeli War," 76 pp., Jun 1978 (Published in Seapower in the Mediterranean: Political Utility and Military Constraints, The Washington Papers No. 61, Beverly Hills and London: Sage Publications, 1979) AD A055 564

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Mizrahi, Maurice M., "Correspondence Rules and Path Integrals," 30 pp., Jun 1978 (Invited paper presented at the CNRS meeting on "Mathematical Problems in Feynman's Path Integrals," Marseille, France, May 22-26, 1978) (Published in Springer Verlag Lecture Notes in Physics, 106, (1979), 234-253) AD A055 536

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Mangel, Marc, "Stochastic Mechanics of Moleculeion Molecule Reactions," 21 pp., Jun 1978, AD A056 227

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Wilson, Desmond P., Jr., "Naval Projection Forces: The Case for a Responsive MAF," Aug 1978, AD AD54 543

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Mizrahi, Maurice M., "The Semiclassical Expansion of the Anharmonic-Oscillator Propagator," 41 pp., Oct 1978 (Published in Journal of Mathematical Physics 20 (1979) pp. 844-855), AD A061 538

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Trost, R. P. and Warner, J. T., "The Effects of Military Occupational Training on Civilian Earnings: An Income Selectivity Approach," 38 pp., Nov 1979k, AD AD77 831

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Mangel, Marc, "Fluctuations at Chemical Instabilities," 24 pp., Dec 1978 (Published in Journal of Chemical Physics, Vol. 69, No. 8, Oct 15, 1978). AD A063 787

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Simpson, William R., "The Analysis of Dynamically Interactive Systems (Air Combat by the Numbers)," 160 pp., Dec 1978, AD A063 760

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Simpson, William R., "A Probabilistic Formulation of Murphy Dynamics as Applied to the Analysis of Operational Research Problems," 18 pp., Dec 1978, AD AD63 761

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Sherman, Allan and Horowitz, Stanley A., "Maintenance Costs of Complex Equipment," 20 pp., Dec 1978 (Published By The American Society of Naval Engineers, Naval Engineers Journal, Vol. 91, No. 6, Dec 1979) AD A071 473

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Simpson, William R., "The Accelerometer Methods of Obtaining Aircraft Performance from Flight Test Data (Dynamic Performance Testing)," 403 pp., Jun 1979, AD A075 226

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Brechling, Frank, "Layoffs and Unemployment Insurance," 35 pp., Feb 1979 (Presented at the Nber Conference on "Low Income Labor Markets," Chicago, Jun 1978), AD AD96 629

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Glasser, Kenneth S., "The d-Choice Secretary Problem," 32 pp., Jun 1979, AD A075 225

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Mangel, Marc and Quanbeck, David B., "Integration of a Bivariate Normal Over an Offset Circle," 14 pp., Jun 1979, AD AD96 471

PP 255 - Classified, AD B051 441L

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Petersen, Charles C., "Third World Military Elites in Soviet Perspective," 50 pp., Nov 1979, AD A077 835

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Robinson, Kathy I., "Using Commercial Tankers and Containerships for Navy Underway Replenishment," 25 pp., Nov 1979, AD AD77 836

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Weinland, Robert G., "War and Peace in the North: Some Political Implications of the Changing Military Situation in Northern Europe," 18 pp., Nov 1979 (Prepared for presentation to the Conference of the Nordic Balance in Perspective: The Changing Military and Political Situation," Center for Strategic and International Studies, Georgetown University, Jun 15-16, 1978) AD A077 838

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Utgoff, Kathy Classen, and Brechling, Frank, "Taxes and Inflation," 25 pp., Nov 1979, AD A081 194

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PP 297 - Classified

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*Northwestern University, Evanston, IL

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Jondrow, James; Bowes, Marianne and Levy, Robert, "The Optimum Speed Limit," 23 pp., May 1981

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PP 335

Lee, Lung-Fei, G.S. Maddala, and R.P. Trost, "Asymptotic Covariance Matrices of Two-Stage Probit and Two-Stage Tobit Methods for Simultaneous Equations Models with Selectivity," 13 pp., Jan 1982. Published in Econometrica, Vol. 48, No. 2 (March, 1980).

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O'Neill, Thomas, "Mobility Fuels for the Navy," 13 pp., Jan 1982. Accepted for publication in Naval Institute Proceedings.

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